ELASTIC DISLOCATION THEORY: INVESTIGATING THE EFFECTS OF THE FREE SURFACE ON THE SYMMETRY OF DISPLACEMENT ACROSS A FAULT

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Abstract

The current model we use for computing dislocation of free surface by earthquakes fault is mostly perfectly planar or perfectly spherical and there is no topography. In real world distance between free surface displacement fault plane varies and does not match up with GPS station in ideal model. To acknowledge exact problem, why this is a big problem, we examined the movement of the free surface and dislocation at right above and below the fault plane in the model we created. This model will have equilateral triangle displacement with 100m length in side horizontal under different depth from free surface. We will also look close to the center of the triangle to see right above and below the displacement surface to see the absolute displacement behavior due to different depth. There was couple of experiment for 1m, 10m, 50m, and 100m. The result was remarkable that it showed huge distinctive difference as the depth changes. The surface displacement showed triangular displacement as we plotted for the fault plane and it emerged out as the depth got deeper. The displacement right above and below the fault plane always had same burger's factor through all depth but absolute vector for above and below the displacement plane had irregular ratio but as the depth goes deeper, it showed almost identical anti-symmetry. The result proves that current model will always derive with biased calculation until we improve or develop new method for dislocation model.

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INTRODUCTION

Earthquakes, and fault dynamics more generally, are represented mathematically using dislocation models for a uniform elastic half-space (Okada, 1985; Meade, 2007), a layered half-space (Wang et al., 2003) or a layered sphere (Pollitz, 1996). In virtually all case, the model surface is perfectly planar or perfectly spherical and there is no topography. But in the real world earthquakes usually occur in places with significant topography, especially subduction zone or megathrust earthquakes where the ocean floor may be 6 km deep, the trench axis even deeper, while the land surface (on which we can make measurements of displacement) lies above sea level, sometimes well above sea level (Fig. 1).

In the real world, the 'free surface' of the solid Earth has considerable topography, and both the GPS stations and the top of the plate boundary or megathrust lie on or very near a free surface. But in a half-space model, if the stations are on the surface, the top of the megathrust lies 6 km or more below the surface (Fig.1A). We can model the rupture of the plate boundary using a dislocation of the correct size, shape and orientation, and with correct position relative to the GPS stations. But this dislocation is not correctly positioned with respect to the nearest free surface (Fig. 1B). We cannot fix that problem without creating an even worse one (Fig. 1c)

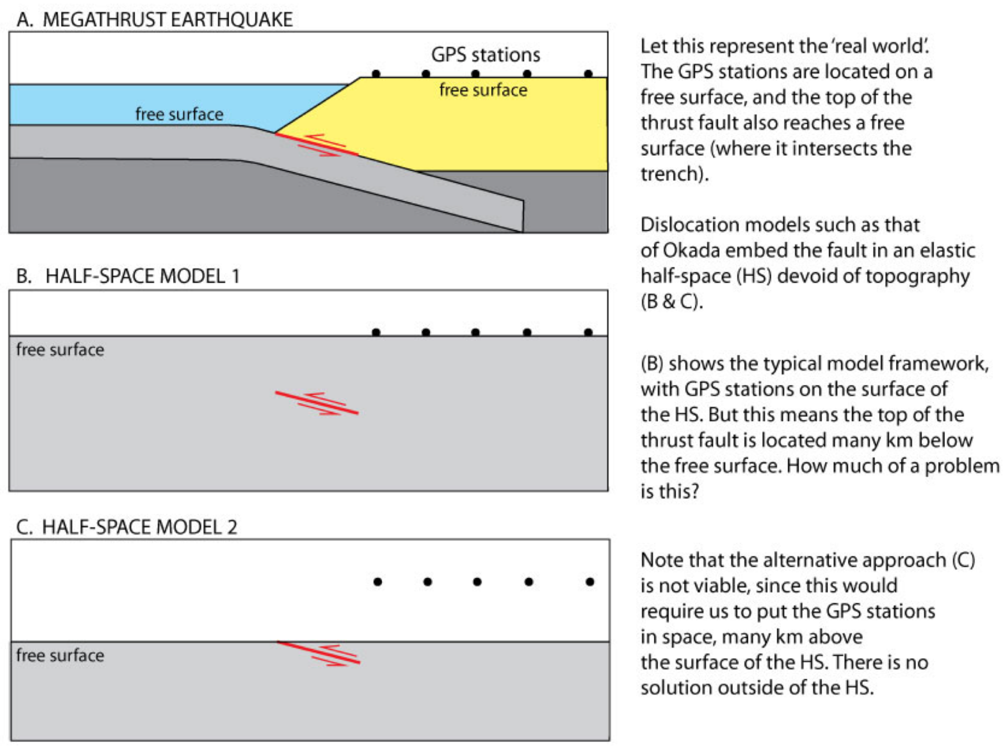

Figure 1: Modeling earthquakes as an elastic dislocation: the problem of free-surface topography

The goal of this project is to characterize the impact that the distance between the dislocation and the free surface has on the elastic deformation field produced by fault slip.

Burger's vector

Dislocation models are set up by specifying the geometry of the dislocation or fault, the geometry of the stations where displacements are to be computed, the elastic properties of the medium in which the fault is embedded, and the fault slip or Burger's vector describing relative motion across the fault (Fig. 2).

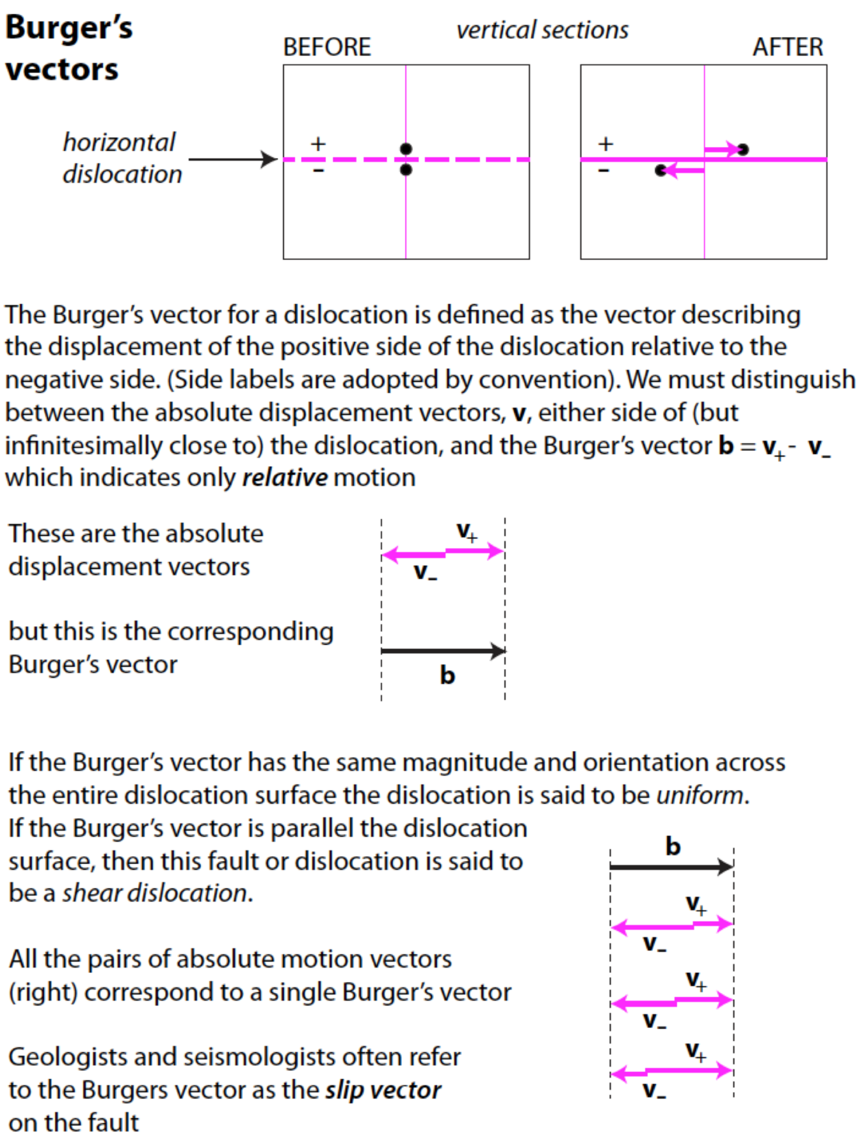

Figure 2. Plots showing the meaning of the Burger's vector for a shear dislocation, and the distinction between relative and absolute displacement of the material either side of the fault or dislocation.

The key issue of interest for us is, given a dislocation of specific size and orientation, and a fixed Burger's vector, how does the pattern of absolute displacement of the two fault walls (either side of the dislocation) change according to the relative position of the dislocation and the free surface?

METHODS

We investigate this issue by considering a horizontal dislocation or fault which in map view has the shape of an equilateral triangle (Fig. 3). Each triangle side has a length of 100 meters. The Burger's vector invokes uniform and horizontal fault slip parallel to the plane of the dislocation. We shall examine the elastic displacements that occur along a vertical line passing through the centroid (or middle) of the triangle, paying particular attention to the absolute displacements occurring just above and just below the dislocation. The computations were carried out using the Matlab code of Meade (2007).

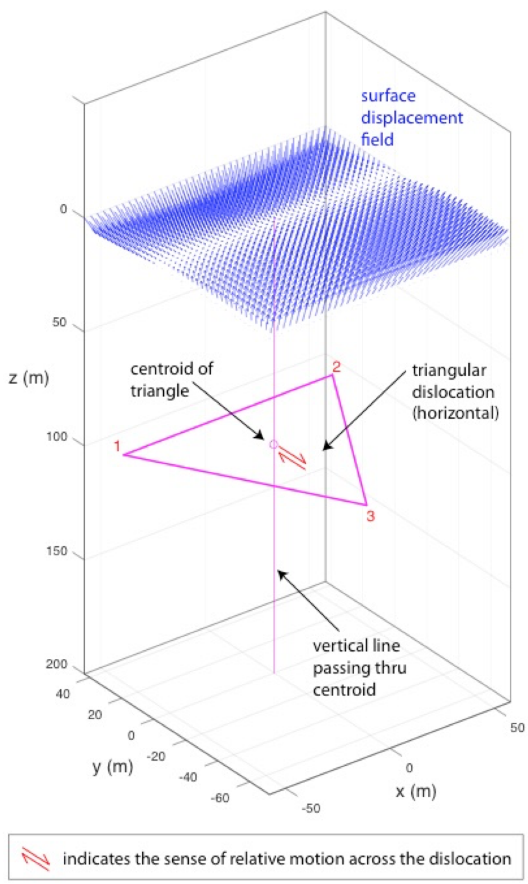

Figure 3. The triangular dislocation used in this investigation.

We performed a series of numerical experiments so as to illuminate the impact of changing the depth of this triangular dislocation.

Results

Figures 4–6 show the surface displacements (vertical and horizontal) induced by 1 meter of fault slip, *i.e.* a fixed Burger's vector, for dislocations with different depths. Young's Modulus for the half-space is assigned a value of 60 GPa, while Poisson's ratio is set to 0.25.

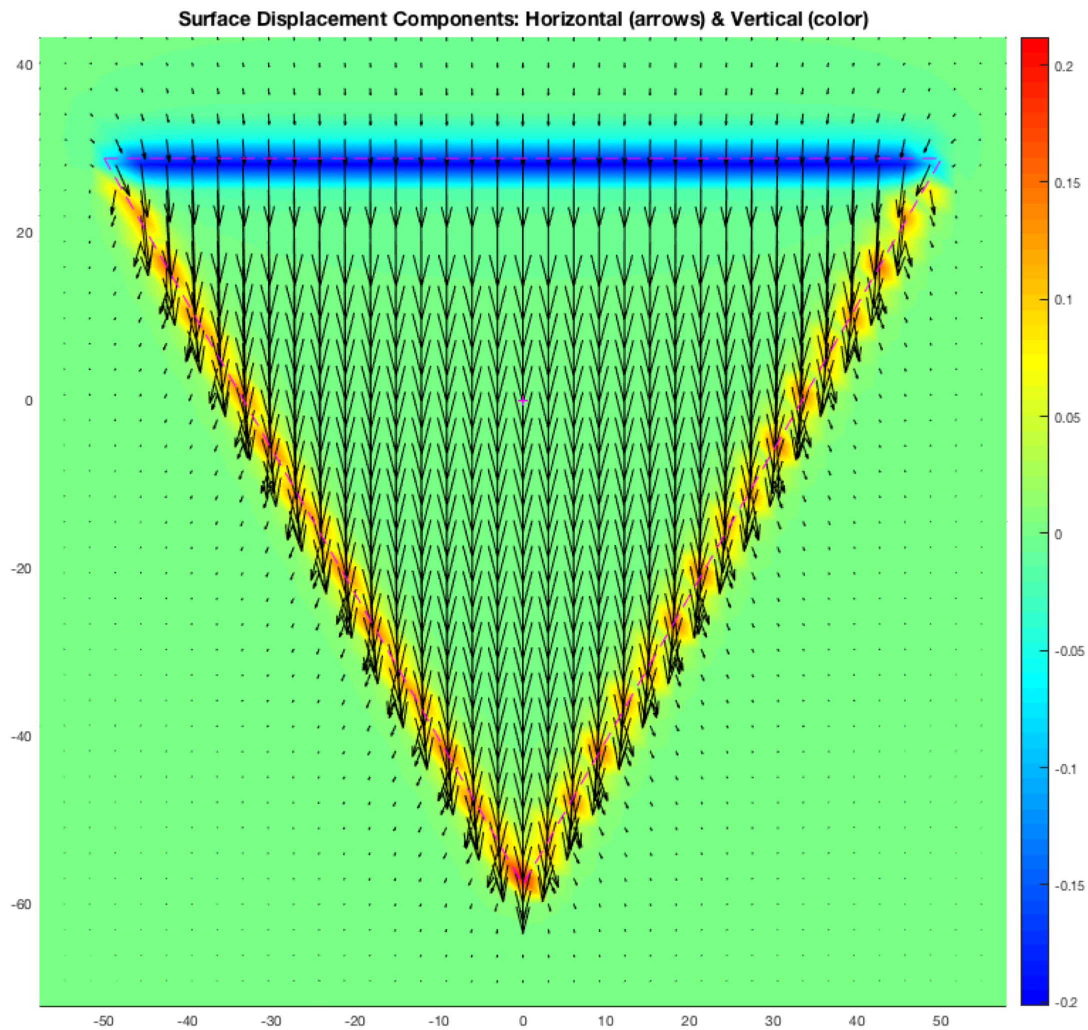

Figure 4. Surface displacements caused when the dislocation has a depth of 1 meter. The vertical displacements (in meters) are colored coded. The arrows depict the horizontal dislocations. The triangular form of the dislocation is easily perceived.

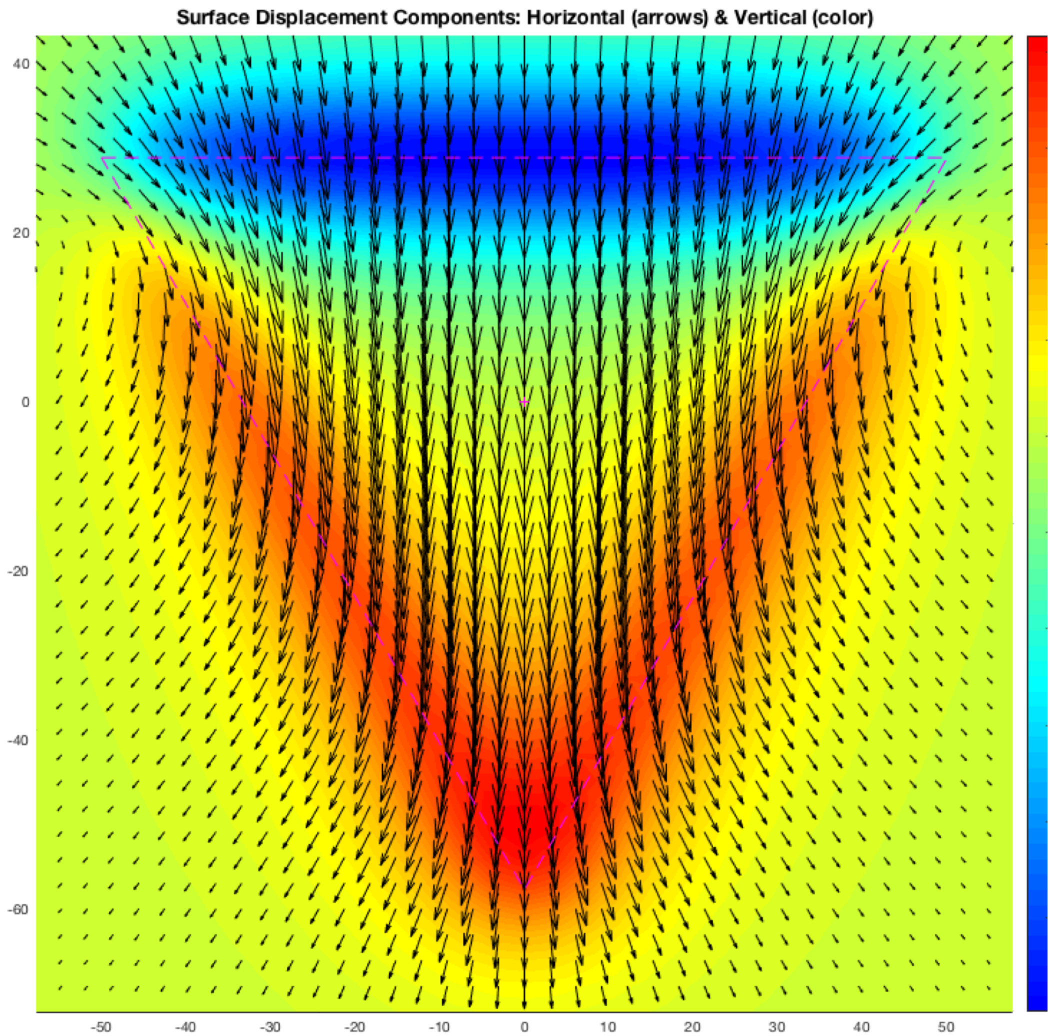

Figure 5. Surface displacements caused when the dislocation has a depth of 10 meters. Again, the triangular form of the dislocation is easily perceived, but not so clearly as before.

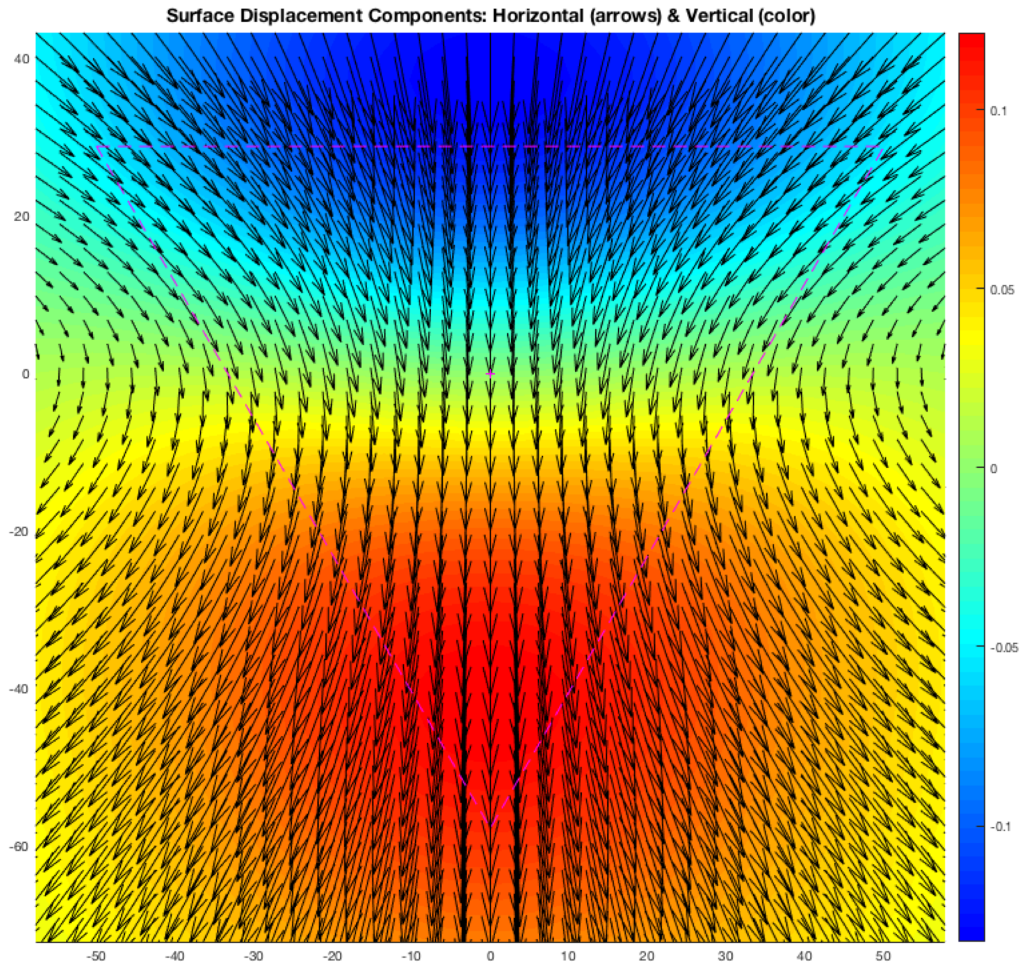

Figure 6. Surface displacements caused when the dislocation has a depth of 50 meters. The triangular form of the dislocation is no longer obvious looking at the surface displacement field.

The fault-parallel displacements that occur above and below the centroid of the dislocation are shown in Figs. 7-10. When the fault depth is 1 meter, the upper wall does most of the moving (Fig. 7). That is, the absolute displacements are extremely asymmetric across the dislocation.

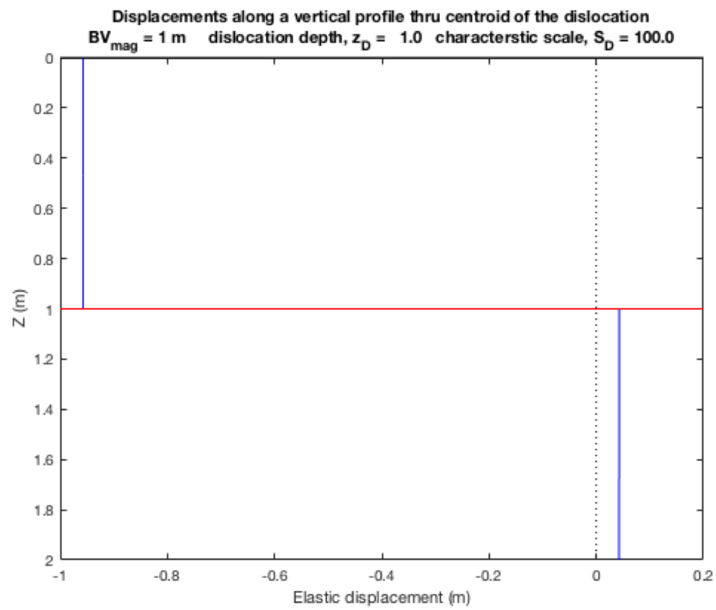

Figure 7. Absolute horizontal displacements (blue curves) above and below the center of the dislocation (red line) when the depth of the dislocation is 1 meter. The wall just above the dislocation has a much larger displacement (0.9572 m) that the wall just below (0.0428 m), but the relative displacement (1.0 m) is just the imposed

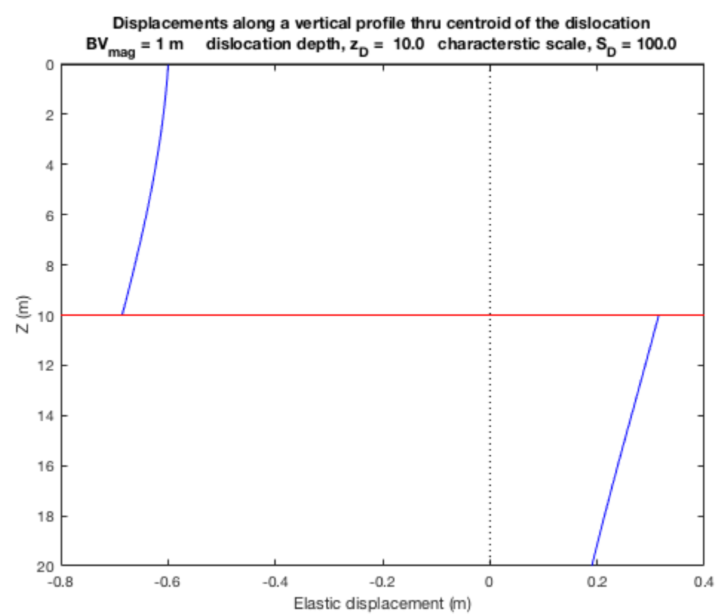

Figure 8. Absolute horizontal displacements (blue curves) above and below the center of the dislocation (red line) when the depth of the dislocation is 10 meters.

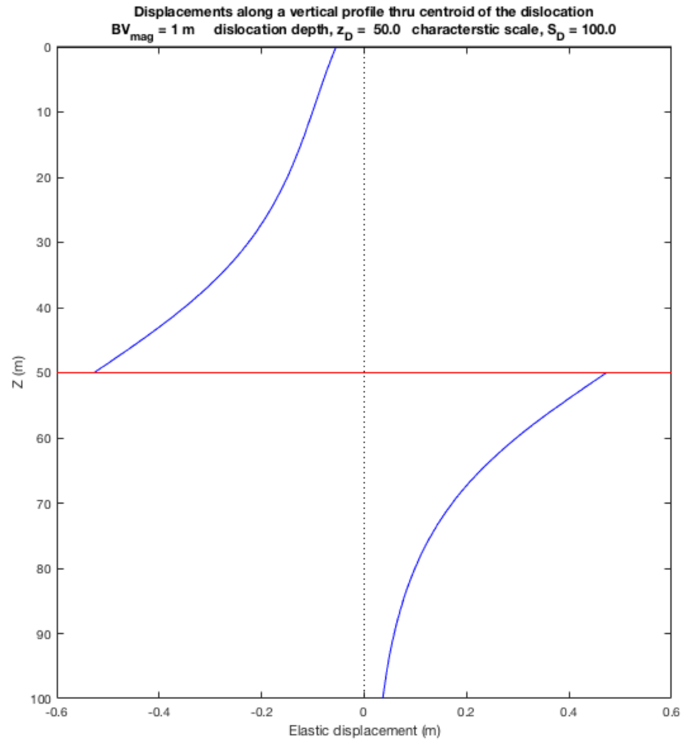

Figure 9. Absolute horizontal displacements (blue curves) above and below the center of the dislocation (red line) when the depth of the dislocation is 50 meters.

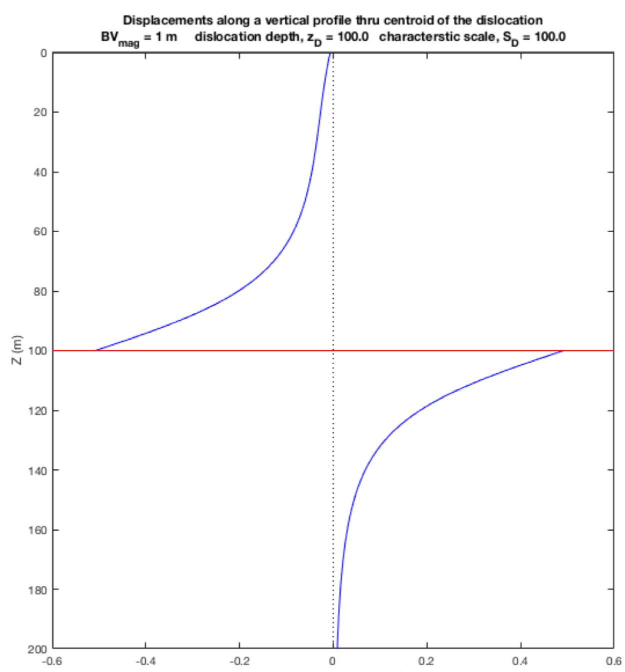

Figure 10. Absolute horizontal displacements (blue curves) above and below the center of the dislocation (red line) when the depth of the dislocation is 100 meters. Now the absolute displacements on either size of the dislocation are very nearly equal and opposite (-0.508m vs +0.492m).

In the event that the dislocation lies 100 m below the surface, a distance equal to the side length of the triangle, the absolute displacements either side of the dislocation are almost equal in magnitude and opposite sign. That is the displacements field very close to the dislocation is almost perfectly anti-symmetric, and the elastic displacement field has split the Burger's vector nearly equally in terms of the absolute motions of the fault walls.

Conclusions

The way in which fault slip (or the Burger's vector field) on a dislocation translates into an elastic displacement field on and within an elastic space is very strongly modulated by the distance between the fault and the 'free' surface of that space, both in our simplified model and in the real solid Earth. When we try to model deformation on a real-world megathrust using a flat Earth or spherical Earth dislocation model, it is inevitable that the distance between the fault and the nearest free surface will be misrepresented. The suggestion is that we need to move towards elastic dislocation models that can incorporate significant topography, and that, until we do so, our inversions of observed GPS displacements will lead to biased estimates of the slip field and the total elastic response to that slip.

Suggestions for Future Work

According to the research, today's displacement model in elastic surface is too simplified, that it does not compute correct result for the real fault space. There needs to develop new families of dislocation models that allow us to incorporate the topography of the free surface of the solid Earth. Physically, it is impossible for GPS stations to locate at every surface, such as below sea level, that it is natural consequence to focus on developing current displacement model. It will be very difficult to obtain new models for the real world, which will contain more variables that will complicate the code. However, as technology improves, it is not impossible to come up with new displacement model that will consider all faults with different depth from free surface or any real Earth spherical model.

REFERENCES CITED

Meade, B. J. (2007). Algorithms for the calculation of exact displacements, strains, and stresses for triangular dislocation elements in a uniform elastic half space. Computers & Geosciences, 33, 1064–1075.

Okada, Y. (1985). Surface deformation due to shear and tensile faults in a half-space. *Bulletin of the Seismological Society of America*, 75(4), 1135–1154.

Pollitz, F. F. (1996). Coseismic deformation from earthquake faulting on a layered spherical Earth. *Geophysical Journal International*, 125(1), 1–14.

Wang, R., Martin, F. L., &Roth, F. (2003). Computation of deformation induced by earthquakes in a multi-layered elastic crust – FORTRAN programs EDGRN/EDCMP. *Computational Geosciences*, 29(2), 195–207.